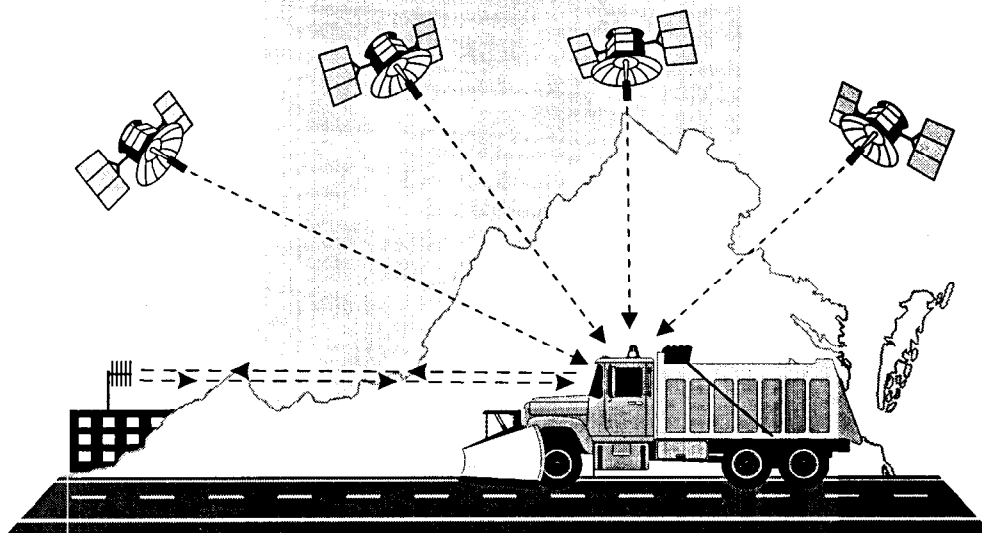


FINAL REPORT

PB2002-107248



LESSONS LEARNED FROM A PILOT PROJECT OF AN AUTOMATIC VEHICLE LOCATION SYSTEM IN AN URBAN WINTER MAINTENANCE OPERATIONS SETTING



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Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 02-R11	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Lessons Learned From a Pilot Project of an Automatic Vehicle Location System in an Urban Winter Maintenance Operations Setting		5. Report Date	
		6. Performing Organization Code	
7. Author(s) Daniel S. Roosevelt, Robert A. Hanson, and William M. Campenni		8. Performing Organization Report No. VTRC 02-R11	
9. Performing Organization and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. UPC 00021721- 6940	
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation FHWA 1401 E. Broad Street P.O. Box 10249 Richmond, VA 23219 Richmond, VA 23240		13. Type of Report and Period Covered Final October 1996 to April 2000	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
<p>16. Abstract</p> <p>This report documents the lessons learned during the evolution of the Virginia Department of Transportation's pilot project to use an automatic vehicle location (AVL) system during winter maintenance operations in an urban setting. AVL is a technology that locates vehicles using a global positioning system, monitors activities associated with the vehicle, transmits the location and activity information to a remote site, and displays the information on maps that are geo-referenced. An AVL system displays real-time information concerning the location and activity of vehicles and archives that information over an extended period for later analysis.</p> <p>The pilot project extended over three winter seasons from 1997 through 2000. Because of operational and institutional issues, system problems, and the mild winters during the life of the study, no financially quantifiable savings could be determined.</p> <p>The researchers concluded that AVL technology tracks vehicles performing winter maintenance operations to an acceptable degree of accuracy in a sufficiently timely manner and offered several suggestions to facilitate implementation.</p>			
17 Key Words Winter maintenance, ITS, AVL, GPS, snow removal		18. Distribution Statement No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 14	22. Price

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

April 2002
VTRC 02-R11

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ABSTRACT

This report documents the lessons learned during the evolution of the Virginia Department of Transportation's pilot project to use an automatic vehicle location (AVL) system during winter maintenance operations in an urban setting. AVL is a technology that locates vehicles using a global positioning system, monitors activities associated with the vehicle, transmits the location and activity information to a remote site, and displays the information on maps that are geo-referenced. An AVL system displays real-time information concerning the location and activity of vehicles and archives that information over an extended period for later analysis.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) is responsible for the maintenance of all interstate, primary, and secondary roads in 93 of Virginia's 95 counties. Maintenance of roads in urban counties presents special challenges. The higher traffic volumes cause maintenance problems to appear and conditions to deteriorate more quickly than on rural roads and reduce the time for effective response. The responsibility for local roads expands the breadth of service delivery required and the public's expectations for service and information. These problems become acute during emergency operations since conditions can change more rapidly than can be adjusted for with the normal tools available to management.

Snow removal and ice control activities are of special concern in urban counties since these events slow traffic on an already congested highway system and adversely affect a large part of the population of the area served. For this reason, VDOT's attention to snow removal and ice control in these counties is greatly out of proportion to its time of actual activity during the year. This is especially true in VDOT's Northern Virginia (NOVA) District.

The NOVA District is responsible for maintenance of the highway system in the predominately urban area adjacent to Washington, D.C. This system includes approximately 17,600 lane km (10,936 lane mi) of interstate, primary, and secondary roads. Traffic volumes range to more than 150,000 vehicles per day at some locations on the interstate system but can also be less than 50 vehicles per day on some subdivision cul-de-sacs on the secondary system. The system grows at a rate of more than 200 lane km (124 lane mi) per year, whereas available VDOT employees and equipment remain level.

To adjust for the increased need for operators and equipment during emergency operations, such as snow events, VDOT hires contract equipment, with operators. Often during a snow removal operation, hired equipment in a maintenance area will outnumber VDOT equipment 3 to 1. The continuing growth of road mileage and traffic volumes, and the

exhaustion of available resources to serve them, has led VDOT to investigate other means to improve management of operations and communications during emergencies. An automatic vehicle location (AVL) system is one management and communications tool that VDOT is investigating.

AVL is a technology that locates vehicles using a global positioning system (GPS), monitors activities associated with the vehicle, transmits the location and activity information to a remote site, and displays the information on maps that are geo-referenced. An AVL system displays real-time information concerning the location and activity of vehicles and archives the information over an extended period for later analysis.

VDOT installed GPS units in 80 trucks operating in two adjacent maintenance areas in the NOVA District. The units reported real-time information about the location of the vehicles and their plowing and chemical spreading activity. The installation was for a pilot test of an AVL system that continued over three winters. The primary purpose of the pilot test was to evaluate the system's effect on (1) the administration of snow removal and ice control contract forces, (2) the provision of information concerning road conditions to the public and media, and (3) the management and performance of snow removal and ice control activities.

PURPOSE AND SCOPE

Although the initial purpose of this study was to test the feasibility of and to quantify the benefits achieved by an AVL system in snow removal operations, the lack of snow removal events of sufficient magnitude to require the long-term operation of the full snow removal fleet made the data collected insufficient for a scientifically based analysis. Other problems, such as system design, operations, and institutional issues, also contributed to this result. The purpose and scope of this report was, thus, modified (1) to describe the system implemented and (2) to discuss the lessons learned during the implementation of the system. The appendix summarizes the planned methodology for the evaluation of the system.

THE SYSTEM

System Description

Since the AVL system was to be part of a pilot program, the NOVA District was tasked with minimizing the AVL system cost while maximizing the opportunity for evaluation of the concept. To evaluate any savings related to management's use of the AVL system, the researchers established one maintenance area as the test area and the other as a comparison area. AVL units were installed in vehicles in both areas. However, management had access only to the information generated and displayed by the AVL system in the test area. To exercise the technology sufficiently within budget constraints, the NOVA District decided to conduct the

pilot project in two maintenance areas that were co-located at the same facility. The configuration of the system is shown in Figure 1.

The pilot AVL program was initiated as a competitive bid contract for which the Orbital Sciences Corporation proposed the winning bid in November 1996. The AVL system consisted of the following:

- 80 GPS tracking receivers (40 units in each maintenance area)
- three networked desktop personal computers installed in three operations and management offices
- differential GPS correction station to provide 5-m (15 ft) positional accuracy
- two-way cellular telephone data and messaging capability
- database of accurate street maps and aerial photos digitized for desktop displays
- data archiving of all captured events for replay and analysis.

Differential GPS correction was needed to provide 5-m (15-ft) positional accuracy because the federal government did not turn off the selected availability until the year 2000. Prior to 2000, GPS positions were altered by the federal government to include significantly more error, resulting in an accuracy that could be determined only within approximately 100 m (328 ft) of the actual position.

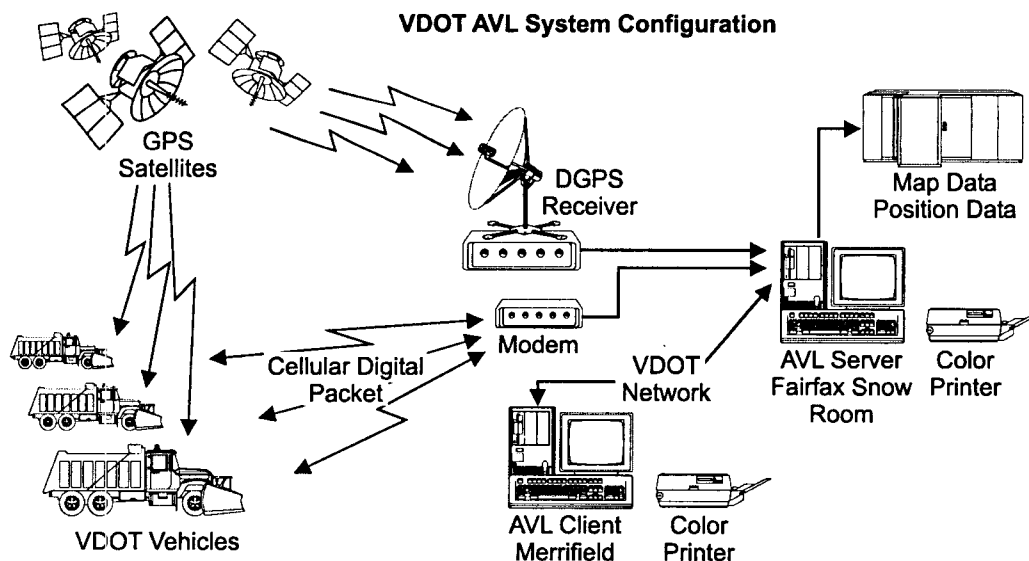


Figure 1. System Configuration of VDOT's AVL

The combined GPS tracking receiver and communication device (referred to as an in-vehicle unit, or IVU) installed in each vehicle is shown in Figure 2. A blowup (actual appearance on computer screen) of the two maintenance areas is shown in Figure 3. These are the two components of the system visible to most operations people using the system.

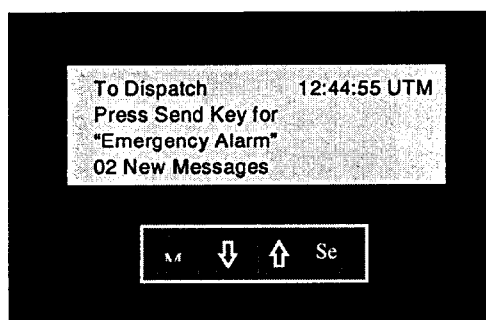


Figure 2. The In-Vehicle Unit

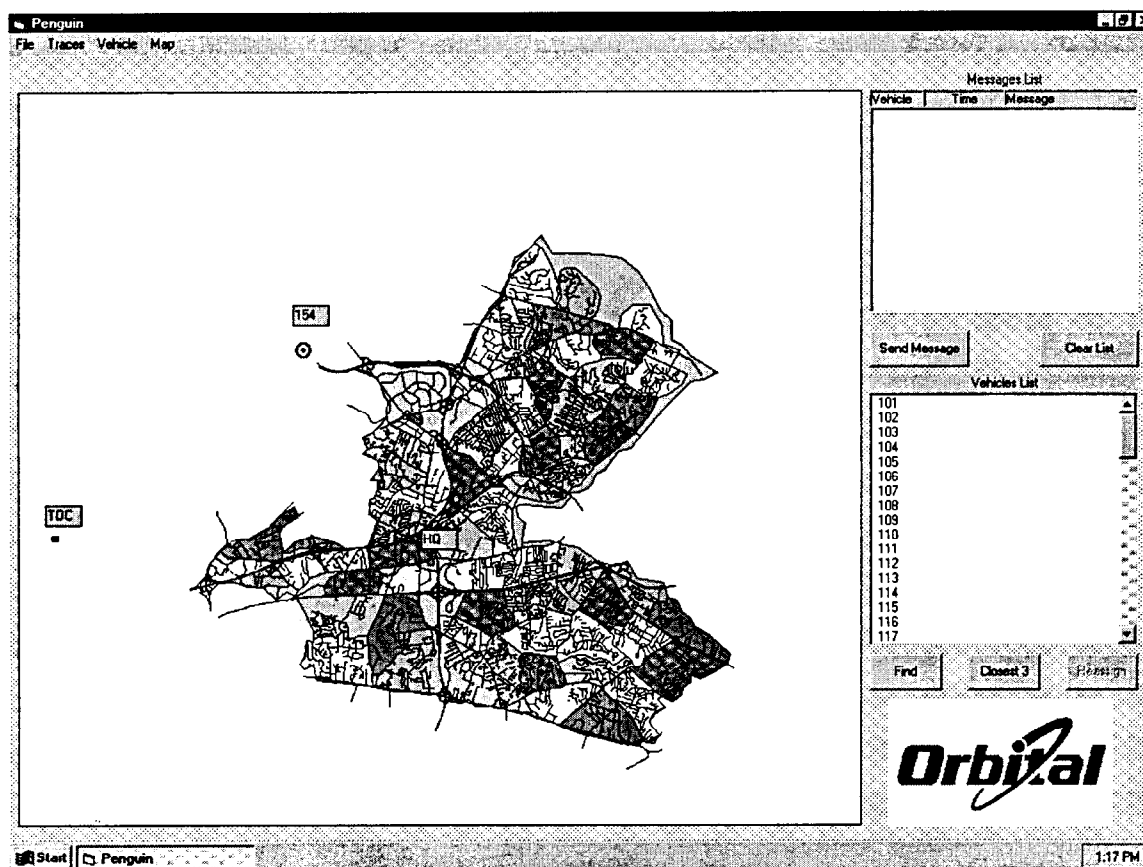


Figure 3. AVL Software Opening Screen

Two remote desktop computers (at the Merrifield Area Headquarters and the Fairfax Residency Snow Room) were networked with the host computer (at the NOVA District Office). All three computers (base stations) could independently monitor the activity of the trucks. Other specifics for the pilot project were as follows:

- The IVU was portable and was removed and reinstalled in different types of equipment. The IVU worked off the vehicle power supply.
- The IVU's signal was differentially corrected at the host computer to report location accurate to 5 m (15 ft), 50% of the time, at vehicle speeds up to 96 km/h (60 mph). This would allow individual lanes and subdivision streets to be discerned from the position reports.
- The IVU sensed three on/off status conditions every 2 s for each vehicle and transmitted this information to the host computer every 10 s. The three conditions sensed were plow up/down, chemical spreader on/off, and vehicle engine on/off.
- The IVU enabled communications between the vehicle operator and the base stations via a readable message system. Each of the base stations could send any free form text message to an individual vehicle or any number of vehicles. The vehicle operator had a series of 30 preprogrammed messages that could be sent to the base stations.
- The AVL system generated real-time displays of vehicle location, traced the route of each vehicle tracked, and color-coded the traces to identify the activity performed.
- The AVL system displayed a variety of geo-referenced raster and vector maps at varying scales.
- All of this information was available in near real time and historically archived for after-action review.

FINDINGS

General

The AVL system was not ready for use until midway into the 1997–1998 winter season. Three snow alerts were activated during the winter. The mild winter that year did not allow a full test of the technology. The pilot program was extended through the 1998–1999 winter season and eventually through the 1999–2000 winter season. The AVL system was used during seven storm events in 1998–1999 and five storm events in 1999–2000, but none was of sufficient magnitude to require the long-term operation of the full snow removal fleet. These alerts did allow a useful test of the system hardware and software and enabled field managers to exercise the basic concept of tracking vehicles. The storm events did not enable the full application of the

AVL system's operational capabilities, such as situational awareness and support for management decision-making and control.

The AVL Technology

Systems Design

Details concerning the AVL system design and installation, and the problems encountered, were not the focus of the evaluation study. A detailed description of this process, and the problems encountered, is contained in the after-storm reports for each of the 15 storm events, the end of season reports for 1997–1998 and 1998–1999, and the end of project report prepared by the VDOT consultant hired for this purpose (Stuart, 2000). Where the design and installation decisions, and the problems associated with them, influenced the evaluation study, they were considered lessons learned and are discussed here.

The pilot-tested AVL system did not perform to expectations until the third winter season. Frequently, the accuracy of the AVL system did not meet the 5-m (15-ft) requirement. The average accuracy was approximately 10 to 15 m. By the third year, this was acknowledged to be sufficient to locate and track the vehicles. The desire to discern specific lanes traversed was acknowledged as more information than could be absorbed during real-time operations.

A design flaw in the tracking feature caused the system to slow down as the volume of stored vehicle tracks increased. During the first two winter seasons, the location and sensor data for each IVU were collected every 2 s (and transmitted to the base computer every 10 s. The first and second winter, the speed of the system update became unacceptable after approximately 1 h of data collection. This problem was resolved during the third winter by a combination of system improvements and decreasing the data collection rate to once every 10 s per IVU (and transmitted to the base computer once every minute). During the first 2 years, the failure of the system to meet the expectations of supplying real-time information on location and activity on a regular basis undermined the confidence of the field personnel and resulted in little reliance on the system at the area headquarters level.

The harsh winter environment in which snowplows operate and the repetitive install/remove operations for the portable units resulted in a higher than expected failure rate (5% to 10% per storm) for wiring and sensor units. The unsecured units (those without a mounting board) moved around in vehicles during operations, resulting in the connecting plugs frequently being disconnected from the back of the IVU, wire breaks, display screen fractures, and antenna lead separations.

The pilot program demonstrated that GPS-based AVL technology could track vehicles with a degree of accuracy and currency to determine location by route at any given time, not only in snow removal operations, but also in other VDOT vehicle operations. Snow removal activities represent the worst-case environment for testing this technology. In snow events, temperature and climatic conditions are at their worst. GPS signals undergo serious electronic signal attenuation and noise effects because of snow on trees and emissions from vehicle radios

and strobe lights. Vehicle-mounted units are subject to significant corrosion, mechanical shock, and fatigue conditions. Although all of these conditions did affect system performance, they did not preclude successful use of the technology over three winters of use.

The installed system was designed in 1996 and installed in 1997. Although the computer hard drive and software were upgraded during the project, in the fast-paced GPS technology, this AVL system is now outdated. It remains useful, however, because it can still be used for snow operations and other services. It would benefit from software upgrades that are available to improve its functionality and performance, but this is generally not be considered for expanded procurements of hardware other than spares and replacements.

Background Mapping

VDOT chose geographically accurate and easily readable maps for the AVL system, one was based on aerial photos and the other on street vectors. The aerial photos are particularly useful in presenting cultural data references not visible on street vector maps. For example, a vehicle may appear to be far off the road when displayed on a street vector map but may be seen actually to be in a parking lot turning around on an aerial photo map.

A map dataset for the AVL application was compatible with other GIS applications. This allowed distribution of the cost and permitted more options for shared use and common display formats for geospatial data. The maps used in AVL should be useful across organizational boundaries, e.g., monitoring by the Safety Service Patrol, police surveillance, highway maintenance, land use, and tax parcels.

Telecommunications

The use of cellular communications links (CDPD) was a near-term choice for the pilot system because it allowed rapid implementation without additional VDOT infrastructure costs for radio antennae and transceivers. CDPD was reaching a limit with 80 vehicles subscribed. Further expansion of the system to more vehicles would require consideration of other communications options or improved CDPD.

Operations and Institutional Issues

The headquarters chosen for the pilot project housed two maintenance areas. Each area was initially assigned 40 vehicles for snow removal. In each area, 30 of the vehicles were contractor trucks hired specifically for snow removal. An IVU was installed in each hired truck at the time it was mobilized for snow removal, and the IVU was removed at the end of each storm event. This created several problems.

IVU-Vehicle-Route Assignment

The actual IVU installation and removal processes took only a few minutes to accomplish. The installation process consisted of connecting two plugs, one for power and one for the sensors, and placing the antenna on the vehicle cab roof. The removal process was the opposite. However, the actual time required to assign and install an IVU took considerably longer because IVUs were initially assigned to specific vehicles. This added considerable time to the installation process as personnel attempted to match a specific IVU to each vehicle. This often occurred under adverse weather conditions and at night, which added many minutes to the process. A new process was subsequently implemented. In the new process, the headquarters system monitor issued IVUs from a central point. The IVU number was recorded and associated with the vehicle on the assignment list. The new process reduced the total IVU assignment and installation time to a few minutes per unit. Once this procedure was adopted, the cost of installation/removal was negligible but created a vehicle identification problem.

Central assignment of the IVUs meant that individual IVUs were randomly assigned to hired trucks. This negated the preseason entry of IVU/vehicle assignment and required the update of the system vehicle information table at the start of each storm. The option adopted was a spreadsheet that listed IVU/vehicle assignment that was referred to each time that information about individual vehicles was needed. This required skills beyond those expected of the AVL monitor.

Although all the state-owned trucks were assigned to a specific route or geographic area, most hired trucks were assigned as they arrived for the snow event. Until the third winter, no written record of assignments was kept. The two areas used a wall-mounted map and numbered tacks to keep track of the assignment of trucks. This required the AVL monitor to copy by hand the truck assignments and enter this information into the spreadsheet used to record the trucks and IVU assignments.

The operational procedure made it difficult for monitors and managers to identify the vehicle assigned an IVU and to determine if the vehicle was on its proper assignment. During the third winter season, a procedure was developed that allowed the area personnel to enter all this information into the spreadsheet list of vehicles as IVUs and route assignments were made. However, this system was not tested since no snow events occurred after this new procedure was put into place.

Even though the issue of tracking IVU vehicle-route assignments was an issue throughout the project, an event-specific spreadsheet prepared by the system monitors allowed them to identify and monitor some vehicles. Considerable anecdotal support for the system did develop, especially in the last year of the project.

Use of Sensor Information

The contract specification called for the AVL system to generate a real-time display of vehicle location, trace the route of each vehicle tracked, and color-code the traces to identify the activity performed. Although the information display of the AVL system met these requirements, the managers and monitors did not use the color-coded information for real-time management decisions. They were interested in the vehicle location but did not rely on the color-coded track, which represented activity. This appeared to be more information than they could absorb and react to, considering the number of vehicles being monitored.

The AVL system archived the activity monitored by the sensors. Although some inaccurate information was recorded, this was determined to be due to faulty wiring of the sensors, not the AVL system. No procedure to tie performance, or compensation, to this activity data was considered.

Two-way Messaging

Two-way messaging was included in VDOT's AVL system as a means of directing the contractor portion of the snow fleet that is not on the VDOT radio network. It was intended that supervisors at the headquarters would send command messages to driver IVUs (start plowing, return to base, etc.) and that drivers would be able to send a limited set of canned messages back to headquarters (finished plowing, I'm lost, yes, no, etc.). In practice, however, two-way messaging was of lesser value to the contractor fleet than to the VDOT state fleet, even though VDOT trucks also had radio. Although the same hired trucks were used during each storm event, the operators employed were often different. The turnover in operators negated the operator training undertaken prior to the winter season and burdened the staff responsible for the AVL system with training the new hired truck operators in the use of two-way messaging as they reported for duty at the start of the storm. This proved to be unfeasible and led to abandonment of the AVL communication system as the preferred form of communication. For contract drivers, AVL messaging proved too complex and mostly unusable, for a variety of reasons, some of which were unforeseeable in the original AVL system design.

On the other hand, there were numerous anecdotal examples of drivers who knew the system using two-way messaging with great efficacy. A simple rule is that if one has regular daily users who are quite familiar with the system, two-way messaging can be a significant benefit.

System Monitors

The headquarters system monitor position was an additional position to the positions usually needed for snow removal operations. Effective use of the AVL system required full-time attention to system during active snow removal operations. This dictated that the system monitor be a dedicated position and not have other administrative duties assigned at the headquarters. The system monitor needed computer operation knowledge and skills to be effective during

emergency operations. In addition, knowledge and skills in system maintenance were valuable, as system maintenance was often needed during operations. During the pilot test, personnel from NOVA's District Information Technology Section were used for both tasks.

Program Management

The AVL system usage was ad hoc. The system was dormant between snowstorms. Inaction spawned problems. Because no one was assigned responsibility for periodically powering up the equipment and checking out the network linkages and connectivity, every snowstorm yielded problems in just turning on the system. IP addresses expired, deleting vehicles from the tracking list; VDOT network passwords expired; unannounced configuration changes were not noticed until operational use was attempted; and IVU units requiring repair were left waiting for pick up, thus unavailable for use in storms. These technical difficulties with the AVL system contributed to low support of the system and a less than successful first and second year of the pilot.

Throughout most of its 3-year pilot, the AVL project lacked a manager with time and authority who could focus on this project to address and fix problems. Although there are many people and organizations using and affected by the AVL pilot program, it was essentially an orphan. Appointment of residency personnel as champions of the project appears to have been a turning point in increased acceptance of the system. As residency management became more involved in the implementation of the system, they became the system's champion. This led to more involvement of the NOVA District Information Technology Section, which resulted in increased technical support for the system.

By the third winter season, because of the new champion, the improvements in the functionality of the pilot AVL system, and increased IT support, field personnel and managers became more comfortable and confident with the use of the system.

CONCLUSIONS

- The pilot AVL system was expensive and is now outdated. Given the advances in the technology and its proliferation, the cost to install a new AVL system is considerably less than that incurred in 1997 by VDOT.
- AVL technology tracks vehicles performing winter maintenance operations to an acceptable degree of accuracy in a sufficiently timely manner. However: (1) good background mapping is extremely important; (2) the determination of lane location is impractical during real-time operation; (3) collection of data on each vehicle every 2 s is not necessary since lane location information is not needed; (4) there is a limit to the amount of sensor information that the system monitors can absorb in a real-time situation; and (5) the temporary installation and removal of IVUs creates problems, i.e., an unacceptable breakage rate on connections and the IVU-100.

- Two-way messaging must be tailored to the user. Although two-way messaging is an important tool, requiring operator responses or inputs while a vehicle is moving is unreliable. Other methods of communications with the operator should be considered instead.
- Logistical support for the system should be a high priority. AVL is an expensive, sophisticated investment that requires considerable attention. The following are needed to implement an AVL system successfully: (1) a project champion with the desire and authority to draw on the resources and shepherd the system through the implementation process; (2) information technology personnel who support the operation of the system; (3) field personnel who fully understand, support, and have ownership of the system; (4) definition of preventive maintenance issues, developed procedures, and personnel assigned responsibility for AVL system operations; and (5) efficient procedures to assign IVU numbers to vehicles and to make assignments in the computer system as the assignments occurred.

RECOMMENDATIONS

- Since the current AVL system is outdated, do not expand it. As IVU equipment breaks down, it should not be replaced if repair requires technical assistance from the equipment vendor.
- Since the AVL technology worked, retain the existing system until its usefulness is gone. The sensors should be abandoned as they break down.
- Since temporary installation of IVUs created problems, permanently install as many as possible in vehicles.
- Use two-way messaging only in the case of an emergency since it diverts equipment operators from their primary objectives.
- Since logistical support is important, include the following in any AVL system implementation: (1) identify a project champion who has the authority to make sure that the necessary resources are made available; (2) ensure that information technology support is available during the operation of the system and to maintain network connectivity; (3) educate, train, and motivate field personnel so that they fully understand, support, and have ownership of the system; (4) define preventive maintenance issues and procedures and identify personnel who will be responsible for AVL system operations; and (5) establish efficient procedures to assign IVU numbers and vehicles to work assignments.

REFERENCE

Stuart AVL Technologies Inc. and Iteris Inc. 2000. *Automatic Vehicle Locating System (AVL) Pilot Program for Snow Removal Operations: End of Program Report*. Richmond, VA.

APPENDIX

EVALUATION METHODOLOGY

The researchers designed the experiment to enable them to determine if the AVL system provided accurate real-time information that would enable management to use available resources more effectively. Specifically, the researchers wanted to determine:

1. financially quantifiable benefits and costs of the AVL system
2. the system's effect on contract administration
3. the system's effect on media and public relations
4. the system's effect on the management and performance of winter maintenance activities.

The method, though not used, is outlined here as background for the lessons learned:

Financially Quantifiable Costs and Benefits

Startup and annual maintenance and operations cost data for the AVL system project were to be collected from VDOT's financial management system.

Startup costs were the costs directly related to the acquisition and implementation of the AVL system. These included capital costs for system equipment and software, preparation and advertisement of the request for proposals; additional equipment (including costs of the sensors, installation of the frame relay) needed for the system that were not part of the contract; and installation of all equipment and initial training costs.

Annual operating costs encompassed recurring related costs, such as communications costs and consulting costs incurred after the system was tested and accepted.

Annual AVL system maintenance costs were the costs associated with the maintenance and replacement of the equipment and sensors and the on-call contract with Orbital Sciences Corporation.

Annual maintenance and operations savings were the savings to VDOT on the expenditures for labor, equipment (both state and hired), and materials resulting from the use of the AVL system. Annual maintenance and operations savings were to be estimated by determining if the system resulted in any improvement in productivity. The researchers determined the sample mean percentages of time vehicles were productive, non-productive, and idle and the sample standard deviations from the sample means for each area. Because GPS data provide positions, and not speeds, the researchers used consecutive position reports and times to determine average speeds. Since GPS position data include error, the researchers were going to

Table A1. Vehicle Status and Sensor Readings

Condition	Engine	Status of Plow and Spreader	Average Vehicle Speed
Productive	On	Plow down, or spreader on, or both	≥ 8 km/h (5 mph)
Non-productive			
Case 1	On	Plow up and spreader off	≥ 8 km/h (5 mph)
Case 2	On	Any combination	< 8 km/h (5 mph)
Idle	Off	Any combination	Any ¹

¹Even though the engine may have stopped and been turned off, errors in GPS data may indicate that a stationary vehicle is moving.

use a minimum average speed of 8 km/h (5 mph) as the threshold to classify a vehicle as moving or not. Table A1 provides the definitions of productive, non-productive, and idle.

Annual social savings were the savings to the public or to the environment. These savings included savings due to reduced number and severity of accidents and reduction in travel times. Accident savings were to be based on the estimated public costs of automobile accidents.

Financially Non-quantifiable Costs and Benefits

The number of scheduled reports submitted was expected to change. The Merrifield Area Headquarters submits four reports to the Fairfax Residency Snow Room at designated times during a storm event. It was anticipated that the AVL system would make one of these reports—the Subdivision Snow Map Update report that indicates the subdivisions where trucks have been assigned and the status of plowing and/or sanding—redundant.

The researchers anticipated that use of the AVL system would reduce the number and duration of two-way radio, telephone, and fax calls between Merrifield Area Headquarters, the test area vehicles and the Fairfax Residency Snow Room.

NOVA District's Traffic Operations Center (TOC) handles all non-VDOT requests for service and information. The plan was to have the TOC monitor the location and activity of the IVU equipped vehicles and use this information to respond to citizens requests for information/service during winter maintenance activity.

Records of anomaly responses and command message responses kept by the TOC were to be reviewed. Where records indicated a start and finish to a problem, an average response time and a standard deviation for responses in the test and comparison areas were to be calculated.